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DAY TO DAY AND PLACE TO PLACE CHANGES IN LOW LEVEL ATMOSPHERIC TEMPERATURE STRUCTURE OFF SOUTHERN CALIFORNIA

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1. INTRODUCTION

The low level atmospheric temperature structure, and in particular the height of the inversion base, is a factor of key importance in the understanding and prediction of marine fog on the West Coast. For example, the conceptual model proposed by Leipper (1948 and 1968) uses this height as a primary index based upon the observation that fog does not form if the base is higher than 1300 feet (400m is now used). Further, it was stipulated that the air above the inversion must be warmer than the underlying sea to provide sufficient overall stability.

There have been a number of studies of the atmospheric inversion over the sea off Southern California. These have shown something of the average state and have provided descriptions of the areal distributions for synoptic situations based upon ship and aircraft surveys. There have also been studies of the time change at fixed points, one from day-to-day over a full year and others from hour-to-hour within the diurnal period, Noonkester (1979) and Mack et al. (1977). These studies all emphasize the great variability of the inversion in space and time and the difficulty of explaining and predicting the changes.

A cooperative field experiment called CEWCOM-'76 provided a unique opportunity to obtain information on both the time and space variation of the atmospheric structure. (See Multi-platform Marine Fog Study, Bulletin of the American Meteorological Society, V. 58, No. 11, November 1977, pages 1226 and 1227). There was a similar experiment in 1978 called CEWCOM-'78. This paper concerns data from those two field experiments and will attempt to show features of atmospheric temperature structure variability in space and time which have some hope of being predictable.

2. PREVIOUS STUDIES

Neiburger, Johnson and Chien (1961) presented synoptic patterns of the inversion base topography and indications of the average characteristics and their distribution off the West Coast. They showed that on the average the base was lowest near the coast and increased both offshore and inland.

Edinger and Wurtele (1971) reported on the results of some 53 flights over the ocean in the area Los Angeles to San Nicolas Island and northward. They concluded for their data on atmospheric structure in the lower levels that "it showed much hour-to-hour and day-to-day variability in which continuity of distinguishing features was difficult to recognize." They showed, for example, that from morning to afternoon in August 1966, the mean change in the depth of the marine layer was as much as 400m in some areas. As to change with distance, the top of the marine layer dropped from 1600m to less than 400m in less than 100 miles on August 18, 1966.

Some of the most comprehensive predictive studies are those of Rosenthal (1973, for example) who analyzed day-to-day variations in the height and strength of the inversion using observations made at San Nicolas Island. He points out that "conventional forecast techniques based on the analysis of synoptic-scale features often offer little help in forecasting day-to-day variations in stratus." (Forecasting low stratus offers the same challenges as forecasting surface fog, the major difference being in the thickness of the marine layer.) Rosenthal was able to relate certain general changes in the structure of the lower atmosphere to broad synoptic events.

An overall review of meteorological problems associated with the West Coast inversion was presented by Schroeder, et al. (1967).

3. AVERAGE AIR TEMPERATURE STRUCTURE AND FOG, CEWCOM 76

The locations of four land stations participating in CEWCOM 76 upper air observations are shown in Figure 1. The stations are San Diego (SAN), Point Mugu (PT. MUGU), San Clemente Island (SCI) and San Nicolas Island (SNI). Also available were raobs from the research vessel Acania of the Naval Postgraduate School. The general area covered by Acania is indicated by the portion of the cruise track shown in the Figure. Acania raobs were made by the Naval Weather Service team.

Boundary layer processes over the sea are greatly influenced by the sea surface temperature. Figure 2 is the pattern obtained by Ralph Markson of MIT from his instrumented aircraft. Mr. Markson coordinated his flights with the Acania and also made vertical soundings of the atmosphere at critical times and places over the sea. For the purposes of the present study it is only significant to note that the coastal sea surface temperature ranged from a low of 19 C in the north to 22 C farther south. Offshore some

30 nautical miles is a tongue of water warmer than 22 C oriented from southeast to northwest. Between this and the coast from latitude 33 N to 34 N is a cool tongue. Overall, the sea surface temperatures in the CEWCOM 76 area are approximately 22 C.

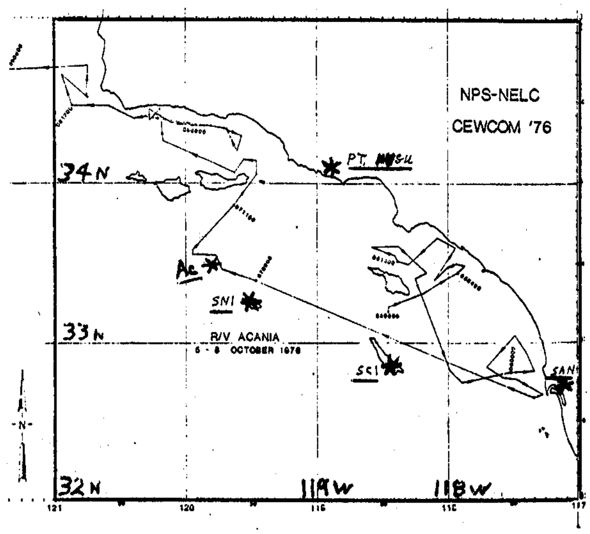

Figure 1. Location map for raob stations and Acania working area for CEWCOM-76.

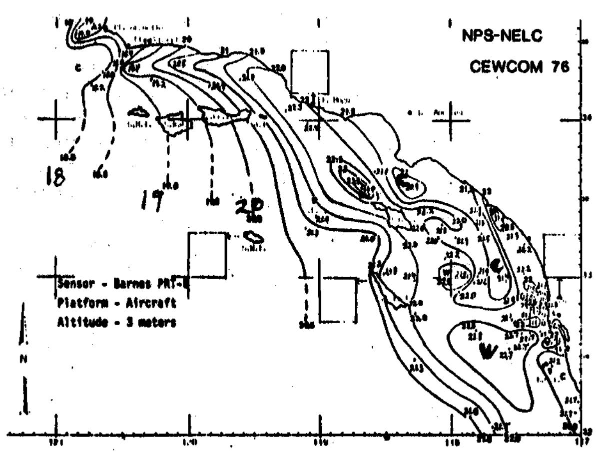

Figure 2. Sea surface temperatures from aircraft remote sensors, from Backes (1977).

The Markson aircraft (Airborne Research Associates) was based in San Diego during the experiment. Daily flights were made from there to the area where the Acania was working and to positions of particular mesoscale interest. An objective here is to demonstrate that, wherever the aircraft and the ship operated during CEWCOM 76, the general synoptic trend from day to day had time continuity which could be shown by changes in the heat content of the air and the height of the inversion base. Relationships of this type were apparently first discussed by Blake (1948, for example). The CEWCOM 76 experiment provided a test of the phenomena over the offshore region, which had not previously been examined.

Over the ocean, it is the heat content of the air relative to the temperature of the sea surface which is significant. On a linear rectangular plot of air temperature against height, the area of the curve above a reference temperature is roughly proportional to the heat content of the air. A good reference temperature is the sea surface temperature. However, for day to day comparisons, the area above the 20 C isotherm conveniently serves. This is used in Figure 3.

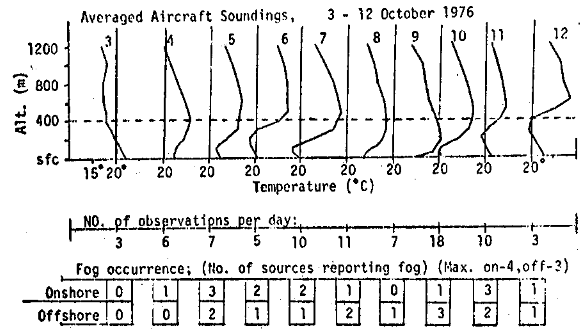

Figure 3. Daily average temperature structure over the sea in the CEWCOM-76 area, from aircraft (R. Markson), and fog occurrence at participating stations, from Backes (1977).

In Figure 3, a large increase in heat content occurred between October 3 and 4. The amount held fairly steady through the 5th and 6th and then increased through the 7th, 8th and 9th. From the 9th through the 11th, it decreased.

When the heat content was steady or decreasing, i.e. the 4th through the 6th and 9th through the 11th, the height of the inversion base, see Figure 3, increased but was always below 400m. It was in these periods that participating stations reported the most days with fog (visibility 1000m or less due to suspended water particles).

When the heat content was greatest, as on October 9, the entire air mass above the sea surface was warm and dry, there was no mixed layer under the inversion, and therefore no fog. When the heat content was least, as on October 3, the overall stability of the air mass was not sufficiently great to permit the development of a strong inversion and thus there was no fog at this time.

The mesoscale synoptic situations for selected days in the CEWCOM 76 sequence are shown in Figures 4 and 5. There is little in these patterns to permit a forecast to be made. Patterns normally available would not be as complete as these, which had the supplemental data and care in analysis resulting from the planned experiment.

4. COMPARISON OF INDIVIDUAL RAOBS FOR DIFFERENT LOCATIONS

There were several days during CEWCOM 76 when four stations on land and the ship made all the raobs. Figure 6 shows selected days when this happened and when there was a change occurring. October 2 was a typical day before the heat increase had begun. All of the air, including the surface, was colder than the sea. The main point of this Figure is to show that, on any given day, the essential features of the soundings which were taken were the same at all stations. This can be said without even considering the position of the Acania which varied throughout the area.

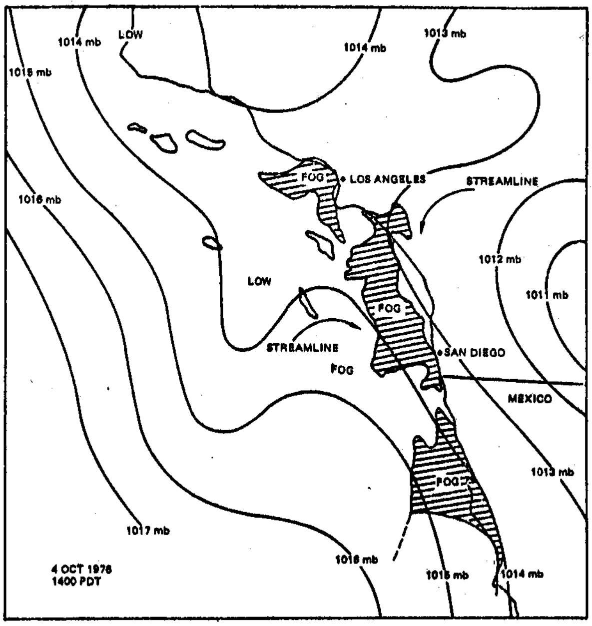

Figure 4. Mesoscale synoptic analysis for 4 October 1976, from Noonkester (1979).

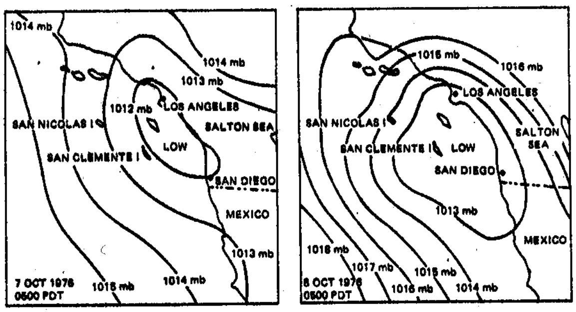

Figure 5. Mesoscale synoptic analysis for 7 October and 8 October 1976, from Noonkester (1979).

By October 4 and 5, the air had become warmer than the sea to elevations greater than 1000m and a mixed layer was present at all locations. On October 8, the heat content had increased to the point that there was little sign of a mixed layer at any station.

It may be noted in Figure 6 that the surface air temperature holds very close to the overall sea surface temperature range near shore as shown in Figure 2.

Figure 7 presents the features of individual soundings taken in different locations on the same day. The Acania was approximately 20 nautical miles northwest of SNI at this time, see Figure 1, and it is the farthest offshore of all the observations at this latitude and northward. It may thus have been at the outer limit of the strongly heated air mass. Both SCI

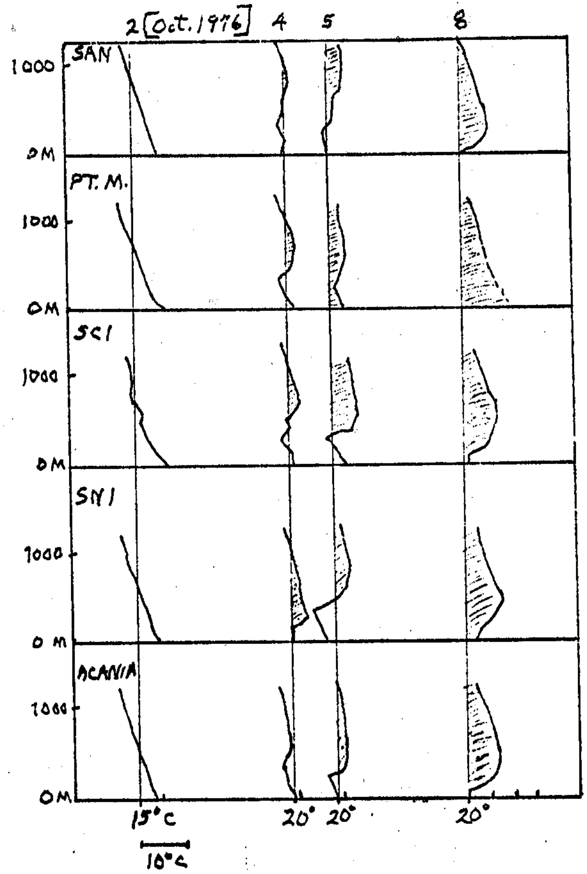

Figure 6. Atmospheric temperature structure from surface to 1200m at participating CEWCOM stations for selected days.

and SNI, which are also offshore, show less heat content than PT. MUGU at the coastline and upwind from them, see Figures 1 and 5.

5. PARAMETERS FOR HEAT CONTENT AND INVERSION HEIGHT

5.1 CEWCOM 76

In practice, in lieu of computing the heat content as an area under the raob curve, the maximum raob air temperature--whether it be at the sea surface or above the inversion base--may be used. To provide the sea surface temperature as a reference, it may be subtracted from the maximum air temperature to obtain what has been called a temperature index (TI). Fog may occur when the TI is positive, if the inversion is lower than 400m, Leipper (1948). (Frontal fogs excepted.)

Figure 8 shows the day to day change in TI throughout CEWCOM 76 for three sets of observations representing two coastal stations and the daily average offshore conditions observed by the aircraft. The trends of these curves are noted to be similar and the values of comparable magnitude at all locations in the CEWCOM 76 area which are represented. The trends may be compared to those shown in Figure 3 and discussed in section 3. The simple TI parameter brings out the essential features of the trends in heat

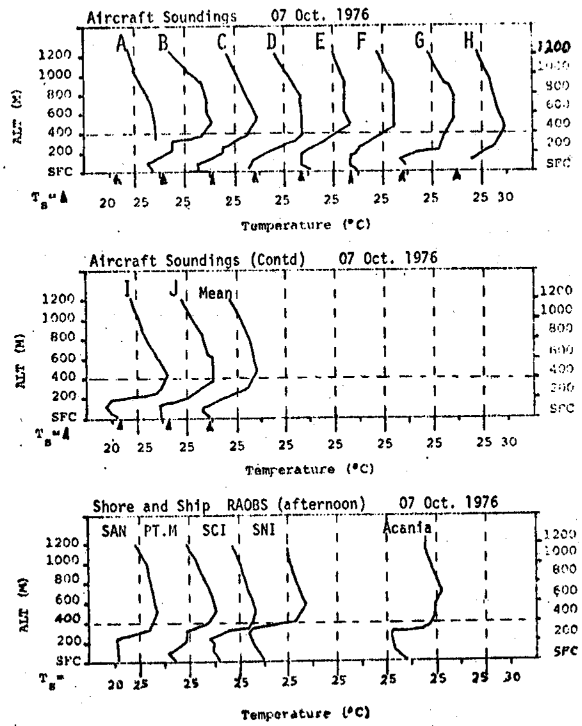

Figure 7. Atmospheric temperature structure from aircraft soundings by R. Markson compared to Acania and shore station data. Aircraft stations A and J near San Diego offshore, stations C, D, E, F, G, H and I near Pt. Conception and station B midway between, from Backes (1977).

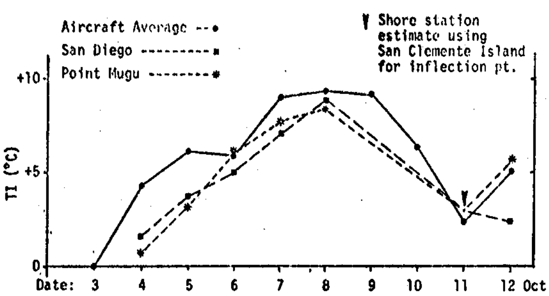

Figure 8. Comparison of the temperature index at shore and aircraft offshore locations. Temperature index (TI) is obtained by subtracting the sea surface temperature from the highest air temperature on the raob.

content.

Also noted in section 3 was the inverse relationship between the heat content and the height of the inversion base. If the TI represents the heat content as a simple parameter, it then follows that the height of the inversion base would increase while the TI was steady or decreasing. It might also be expected with some support from Figure 3, that the inversion height might decrease during periods of days when the TI was increasing.

5.2 CEWCOM 78 and Parameters

CEWCOM 78 was an experiment very similar to its 1976 predecessor. It was conducted in the same general area with many of the same stations and agencies taking part. However, CEWCOM 78 was in the spring from May 10 to 23, 1978.

The completely independent set of raobs taken for the second experiment may be plotted to test, as a second example, the time continuity and the inter-relationships of the parameters utilized in the 76 analysis. The result is Figure 9.

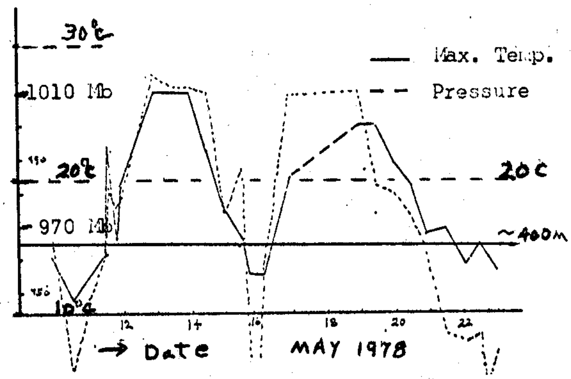

Figure 9. Day by day comparison of the atmospheric pressure at the base of the inversion (which, in the inverse, is nearly proportional to the height of the inversion base) to the maximum air temperature on the raob. Observations from the Acania in the CEWCOM 78 area.

The height of the inversion base may be computed from the atmospheric pressure and other variables. However, for fog-stratus conditions, the atmospheric pressure at the top of the mixed layer may be taken as proportional to the height of the inversion base. This is done in Figure 9. The pressure of 965 mb would be roughly equivalent to the critical inversion height of 400m.

Since the sea surface temperature over the CEWCOM-78 area had a range much smaller than the range of maximum air temperature on raobs, the maximum air temperature value itself could be used in lieu of the temperature index (TI). Thus, for these ranges of inversion height and air temperature, Figure 9 displays a remarkable relationship between the two for the CEWCOM 78 period and area. Again, in this graph, the position of the ship from which the raobs were taken is not noted other than that it was operating in the experimental area. The fact that position can be ignored is a good indication that the features being dealt with are of a synoptic mesoscale nature and have good time continuity.

If it be assumed that the lower inversions are associated with the offshore flow of warm, dry air and that the deeper mixed layers are more typical of the undisturbed marine environment, then observations made on the Acania of Radon 222 are interesting, Larson, Kasemir and Bressan (1979). These showed that there were two significant periods within CEWCOM 78, each lasting some 30 hours, when concentrations typical of continental air were present. These periods were centered on the mornings of May 10 and May 15. These were the only two periods during the observations when the inversion base rose above 400m.

6. CONCLUSION

Data from two CEWCOM experiments have been utilized to illustrate the time and space continuity of parameters related to fog off Southern California. The height of the inversion base has been indicated to be inversely proportional to the heat content of the lower 1000m of the atmosphere when the air is warmer than the sea. Both of these quantities and parameters related to them were observed to be of similar magnitude over areas of 100s of kilometers and were observed to vary from day to day in a smooth and continuous manner, giving some hope of predictability.

7. CREDITS

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